



Utilisation of Biochar from Kapok Randu (*Ceiba pentandra*) Branches for Decolourisation of Remazol Red in Water

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Abstract

Synthetic dyes such as remazol red are commonly used in the batik process, but their residual waste is a major contributor to water pollution. These effluents can degrade water quality, damage aquatic ecosystems, and pose health risks to humans. This research aims to reduce these problems by using an adsorption method that utilises kapok randu branch as an adsorbent for remazol red dye. Kapok randu branches were pyrolysed at temperatures of 400 °C, 450 °C, and 500 °C. This study aims to measure the ability of biochar from kapok randu branches to adsorb remazol red dye under varying weight, time, and pH conditions. The results showed the characteristics of kapok randu branches biochar include moisture content of 400 °C, 450 °C and 500 °C biochar of kapok randu branches of 5.56%, 5.01% and 4.80%, respectively. The ash content of the 400 °C, 450 °C, and 500 °C kapok randu branch biochar was 5.68%, 6.66%, and 7.24%, respectively. The maximum weight of kapok randu branch biochar in adsorbing remazol red dye is 25.00 mg with an adsorption capacity of 0.31 mg/g. The maximum contact time required was 60 minutes with an adsorption capacity of 1.00 mg/g. The maximum pH for the remazol red dye during the adsorption process was at pH 4, with an adsorption capacity of 5.82 mg/g.

Keywords: Adsorption; biochar; kapok randu branches; remazol red

Introduction

Wastewater containing synthetic dyes is a significant pollutant in the environment, especially in areas with textile and handicraft-based household industries. Liquid effluents are almost always a by-product of the textile industry. These effluents contain harmful contaminants that pose a significant risk to the environment, particularly aquatic ecosystems. The production process in this sector requires a considerable amount of water. In addition, most of the pollution in textile effluents is caused by dyes, especially synthetic dyes (Firmansyah, 2023). There are various types of synthetic dyes used in the textile industry, such as Remazol red dyes. The choice of synthetic dyes is based on the need for a fast, practical process. The use of synthetic dyes is also more economical, and the resulting colours are more durable and less likely to fade (Subagyo, 2021). Wastewater from the textile industry can harm living organisms by causing carcinogenic, genotoxic, cytotoxic, and allergic effects (Azanaw et al., 2022). Textile mills discharge large volumes of liquid waste containing toxic and hazardous materials, posing a serious threat to the environment. When these chemical wastes are released into the air, water or soil, they

spread quickly and can contaminate the surrounding area extensively (Rezki et al., 2024). Innovation in effective, environmentally friendly waste treatment technology is urgently needed to reduce the impact of such pollution.

Biochar, also known as charcoal, is the product of heating biomass waste, such as agricultural waste, in airless conditions or with very little air. This charcoal production process is often referred to as pyrolysis. Biochar is characterised by a large specific surface area, abundant surface functional groups, and mineral components (Purwardi, 2024). Biochar has been widely studied as an adsorbent in wastewater treatment due to its porosity, low cost, and ease of availability. In general, biochar feedstocks used include corn stalks (Walanda et al., 2022), cassava stalks (Redjeki et al., 2023), oil palm empty signs (Ramadhan, 2025) and other biomass wastes. However, the utilisation of kapok randu, which has only been used for its fibre and wood in the textile industry and as building materials, remains very limited as a source of biochar for wastewater treatment, especially for synthetic dyes (Pratama et al., 2025).

Kapok randu is a tropical tree species that can grow in Asian regions, such as Malaysia, the

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Philippines and Indonesia, including in Dalaka Village, Sindue District, Donggala Regency, Central Sulawesi. Historically, most people in this village also depended on the processing and craftsmen who made kapok-based products. However, the utilisation of organic waste from this tree is often not maximised. The characteristics of this plant include roots that spread and are visible on the soil surface, a green, sometimes spiny trunk, and irregularly branched branches (Laksmi et al., 2023). The kapok randu tree can reach a height of 8 to 30 meters, with a large-diameter trunk that measures about 3 meters. The trunk is equipped with large, cone-shaped spines (Anggraeni et al., 2024). Kapok randu has a lignocellulosic composition of 32% hemicellulose, 38% cellulose, and 20% lignin (Andahera et al., 2019). This makes kapok randu a potential raw material for biochar production.

Research on biochar from kapok randu as an adsorbent for dye decolourisation in water remains very limited. However, research has shown that biochar from kapok randu can adsorb synthetic pollutants. However, the specific application of biochar from kapok randu for decolourisation in the domestic environment of the Dalaka Village community has not been widely found in the scientific literature (Napitupulu et al., 2025). Until now, similar studies have mostly used other agricultural wastes and have not explored the specific potential of kapok randu, which grows abundantly in Donggala. In fact, the utilisation of this kind of local waste presents a significant opportunity to develop resource-based solutions, support a circular economy, and strengthen the region's ecological resilience.

Research into the utilisation of biochar from kapok randu as a decolourisation agent offers a cheap and environmentally friendly, local resource-based solution. By utilizing local waste, this research contributes, among others, to increase scientific knowledge related to the adsorption performance of randu kapok biochar and the mechanism of decolorization of remazol red dye in wastewater; filling the research gap in the development of randu kapok waste-based water treatment technology at the household or community scale, especially in Donggala; providing alternative solutions for household wastewater treatment that are easily adopted by the community, thereby improving local environmental quality; and supporting circular economy practices and community empowerment in waste management into value-added products (Silalahi et al., 2023).

Methods

The research conducted was to make biochar from kapok randu branches as an adsorbent to determine the maximum weight, contact time and pH suitable for adsorbing remazol red dye.

Research tools and materials

Tools

The tools used in this research include digital balance (Sonic), analytical balance (Beadam), furnace (Nabertherm), oven (Mettler), desiccator (Iwaki), gegeg, beaker (AGC Iwaki), porcelain cup, mortar and pestle, 80 mesh sieve, stirring rod, erlenmeyer (Schott Duran), measuring cup (Pyrex), volumetric flask (Iwaki Pyrex), volumetric flask (Iwaki Pyrex), shaker (Gemmy), drop pipette (BHQ), volume pipette (Iwaki), suction rubber (D&N), spray bottle, spatula, watch glass (Pyrex), funnel (Pyrex), pH meter (LaMotte), FTIR bruker alpha II ECO-ATR, UV-Vis spectrophotometer (PG Instruments Ltd).

Materials

The materials used in this research include kapok randu branches, remazol red dye, distilled water, filter paper, aluminium foil (Total Wrap), label paper (basic), tissue (paseo), pH 4 buffer solution, pH 7 buffer solution, and pH 10 buffer solution.

Research procedures

Raw material preparation and pyrolysis temperature setting

Samples were taken from kapok randu trees and cut into pieces, then the kapok randu branches were cleaned by washing with water and dried in the sun for 48 hours. Afterwards, the kapok branches were placed in the furnace at 400 °C, 450 °C, and 500 °C for 1 hour. After pyrolysis, the sample was cooled to room temperature and then pulverised using a lump and a pestle. Furthermore, it was sieved using an 80 mesh sieve (Novita et al., 2021).

Moisture content determination

The sample of kapok randu biochar was weighed up to 2 grams and placed in a porcelain cup with a known weight. The sample was heated using an oven at 105 °C for 30 minutes. After that, the sample was cooled in a desiccator and weighed again until its weight was constant. Moisture content was calculated using formula 1.

$$\% \text{ Moisture content} = \frac{A-B}{A} 100\% \quad (1)$$

Description:

A = Initial biochar weight (grams)

B = Final biochar weight (grams)

(Fitriansyah et al., 2021).

Moisture content content

2 grams of the sample is placed in a porcelain cup that has a known weight. The sample was then heated in the oven at 105 °C for 1 hour, after which it was ignited in a furnace at 650 °C for 4 hours. The resulting ash was cooled in a desiccator and weighed until it reached a constant weight. Ash content was calculated using formula 2.

$$\% \text{ Ash content} = \frac{B}{A} \times 100\% \quad (2)$$

Description:

A = Initial biochar weight (grams)

B = Ash weight (grams)
(Fitriansyah et al., 2021).

Preparation of mother liquor and standard solution of remazol red dye

Weigh 0.25 grams of remazol red dye. Then add the remazol red dye to a 250 mL measuring flask. Then, distilled water was added to the limit mark and stirred until homogeneous, yielding a 250 ppm remazol red parent solution. From the 250 ppm remazol red standard solution, remazol red series standard solutions with concentrations of 5, 10, 15, 20, and 25 ppm were made. A total of 0.2, 0.4, 0.6, 0.8, and 1 mL of the parent solution was added to each 10 mL volumetric flask, the flasks were diluted with distilled water, and then homogenised. The absorbance of the solution was then measured using a UV-Vis spectrophotometer at 520 nm. The absorbance results were used to prepare the calibration curve (Saraswati, 2022).

Maximum weight determination

Four erlenmeyers were each filled with 25, 50, 75, and 100 mg of biochar. Then, each Erlenmeyer was filled with 10 mL of remazol red dye. Then erlenmeyer covered with aluminium foil and stirred using a shaker for 1 hour. It was allowed to stand for 15 minutes, until a residue formed at the bottom of the Erlenmeyer flask. Then the filtrate and residue were separated using filter paper and analysed using a UV-Vis spectrophotometer at 520 nm (Yuliafitri & Swistoro, 2024).

Determination of maximum contact time

Five Erlenmeyer flasks were each filled with the maximum mass obtained previously. Then, each Erlenmeyer was filled with 10 mL of remazol red dye. Then the Erlenmeyer flask was covered with aluminium foil and shaken for 20, 30, 40, 50, and 60 minutes. It was allowed to stand for 15 minutes, until a residue formed at the bottom of the Erlenmeyer flask. Then the filtrate and residue were separated using filter paper and analysed using a UV-Vis spectrophotometer at 520 nm (Yuliafitri & Swistoro, 2024).

Determination of maximum pH

Remazol red dye was taken in 10 mL and divided into three different Erlenmeyer flasks. Then the pH of the remazol red dye is adjusted by adding a few drops of pH buffer 4, 7, and 10 to each solution. Furthermore, remazol red dye was mixed with the maximum amount of kapok randu branch biochar added to the Erlenmeyer flask. The Erlenmeyer flask is closed with aluminium foil, and the shaker is used for the maximum time previously obtained. Let it stand for 15 minutes until a residue forms at the bottom of the Erlenmeyer. Then filter and test the filtrate using a UV-Vis spectrophotometer at 520 nm (Yuliafitri & Swistoro, 2024).

Data analysis

The data obtained from the adsorption capacity (Q) and adsorption power (% adsorption) equations (Afandy & Sawali, 2024).

$$\% \text{ Adsorption} = \frac{C_i - C_{eq}}{C_i} \times 100\% \quad (3)$$

$$C_b = C_i - C_{eq} \quad (4)$$

$$Q = \frac{(C_i - C_{eq}) \cdot v}{m} \quad (5)$$

Description:

Q = Adsorption capacity (mg/g)

C_i = Initial concentration of dye (mg/L)

C_{eq} = Concentration of dye at equilibrium (mg/L)

C_b = Concentration of adsorbed dye (mg/L)

V = Volume of solution (L)

M = Maximum adsorbent mass (grams)

Results and Discussion

The dried kapok randu branches were pyrolysed at 400 °C, 450 °C, and 500 °C. Pyrolysis temperature is an important factor in determining the structure and function of biochar, including surface area, particle size, porosity, functional group content, and adsorption capacity. The higher the pyrolysis temperature, the smaller the biochar particle size tends to be, and the surface area and pore volume increase drastically due to the breakdown of organic compounds such as hemicellulose, cellulose, and lignin, thereby forming new channels and pores in its structure (Chatterjee et al., 2020).

Moisture content and ash content

The measurement of moisture content aims to determine the hygroscopic properties of biochar. This hygroscopic property illustrates biochar's ability to absorb moisture from its surroundings, thereby affecting its adsorption efficiency and capacity (Pramudita et al., 2025).

Tables 1 and 2 show the moisture and ash content of kapok randu branches obtained through pyrolysis at different temperatures. The percentage water and ash content of kapok randu branch biochar meets the quality standards of SNI 06-3730-1995, with a maximum water content of 10 % and a maximum ash content of 15 %. This indicates that all kapok randu branch biochar, across the three pyrolysis temperature variations, can be used as an adsorbent.

Table 1. Moisture content of the randu kapok branch biochar

Pyrolysis Temperature (°C)	Moisture Content (%)	SNI 06-3730-1995
400	5.56	10 %
450	5.01	10 %
500	4.80	10 %

On the other hand, ash content measurement aims to determine the percentage of mineral matter in the organic substances remaining after pyrolysis. Ash content provides an important insight into the quality of an adsorbent. High ash content can indicate the presence of contaminants that clog the adsorbent's pores, thereby reducing its adsorption capacity (Asmunandar et al., 2023).

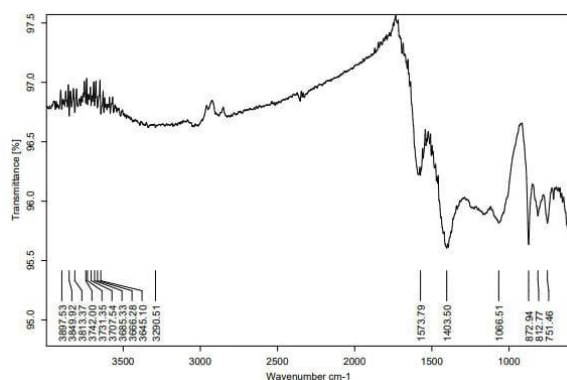
Table 2. Ash content of the randu kapok branch biochar

Pyrolysis Temperature (°C)	Ash Content (%)	SN1 06-3730-1995
400	5.68	15 %
450	6.66	15 %
500	7.62	15 %

The water content decreases as pyrolysis temperature increases because more water in the raw material evaporates during heating, making the produced biochar drier (Aini et al., 2023). While the ash content in biochar increases with pyrolysis temperature, at high temperatures, organic compounds evaporate and decompose, reducing organic content. At the same time, inorganic minerals are not burned, and a solid residue remains (Asmunandar et al., 2023).

Fourier transform infrared spectroscopy analysis.

Biochar from kapok randu branches was studied using Fourier transform infrared spectroscopy (FTIR) to identify hydroxyl and carbonyl functional groups. This analysis was carried out in the wave number range of 3500-1000 cm^{-1} (Figure 1).


Figure 1. FTIR spectrum of randu kapok branch biochar

Based on the FTIR spectrum obtained, it can be seen that the functional groups contained in the kapok randu branch biochar are aromatic C=C functional groups found at a wavelength of 1573.79 cm^{-1} , C-N functional groups found at a wavelength of 1403.50 cm^{-1} , C-O stretching functional groups found at a wavelength of 1066.51 cm^{-1} , and C-H bending functional groups of aromatic compounds found at a wavelength of 812.77 cm^{-1} – 751.46 cm^{-1} .

The C=C bond derived from the aromatic ring is one of the characteristic groups in biochar that provides chemical stability and a large surface area. This aromatic group can interact with other aromatic compounds through $\pi - \pi$ stretching interactions. The C-N and C-O groups indicate the presence of nitrogen- and oxygen-containing functional groups with polar properties and the ability to form electron-donor-acceptor bonds with other molecules. In the randu kapok v ranch biochar, a C-H bond indicates the presence of hydrocarbon compounds in the sample. The C-H

functional group is known to arise from organic compounds such as cellulose, hemicellulose, and lignin that remain in biochar after pyrolysis (Nurjannah et al., 2020). This is consistent with research on the adsorption of rhodamine B dye by adsorbents, in which FTIR results indicate the presence of groups that play an important role in the adsorption process, such as aromatic C=C and C-O bonds (Habib et al., 2025).

Biochar maximum weight analysis

The maximum adsorbent weight ensures there is enough surface to adsorb the maximum amount of adsorbate. The effect of adsorbent weight was tested at four levels: 25, 50, 75, and 100 mg (Figure 2).

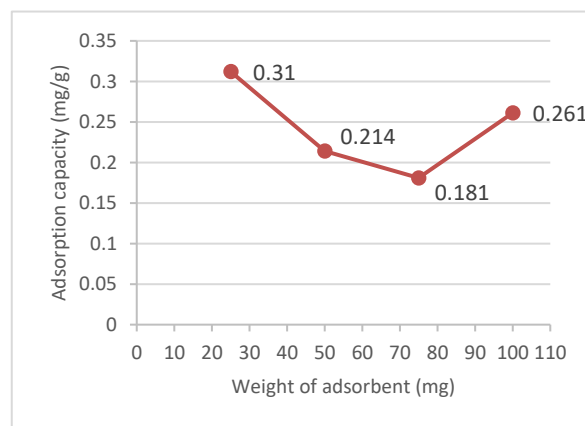

Figure 2. Relationship curve between adsorbent weight variation and the adsorption capacity of remazol red dye

Figure 2 shows that remazol red waste has decreased adsorption capacity at biochar masses of 25-75 mg. However, at a biochar mass of 100 mg, the adsorption process increased. This is due to the adsorbent's instability during adsorption. In this adsorption process, it is assumed that the active sites on the biochar surface (such as C=C, C-N, C-O, and C-H aromatic groups) are maximally available to interact with dye molecules through van der Waals forces. When the mass of the adsorbent is too high, although the total number of active sites increases, the possible build-up or coalescence of biochar particles can hinder the access of dye molecules to these sites, so the efficiency per gram of adsorbent decreases. In this force, there is also a reversible reaction that allows the release of remazol red dye that has been adsorbed back into the remazol red solution, resulting in an unstable curve (Oko et al., 2022). The data show that 25 mg is the optimal amount for removing remazol red from the solution.

The results of this study differ from previous literature on the adsorption of remazol brilliant blue R dye, where absorption increases with increasing adsorbent weight and then drops as adsorbent saturation is reached. This difference can be attributed to the characteristics of the biochar and the process conditions used. Nevertheless, both indicate that there is an optimal adsorbent mass that maximises adsorption capacity, beyond which

adding more adsorbent mass no longer significantly increases adsorption efficiency (Siswanti et al., 2023).

Analysis of biochar maximum contact time

The maximum contact time must be calculated to determine the duration required for the adsorbent to adsorb the adsorbate optimally. The adsorption process usually reaches equilibrium within a certain time. The increasing x/m value indicates that the adsorption process depends on contact time, with the biochar binding more adsorbate over time. In the first 20 to 40 minutes, adsorption occurs rapidly, as evidenced by the increasing x/m value. Then, at minute 50, it decreased, then increased again and reached its maximum at minute 60 (Figure 3).

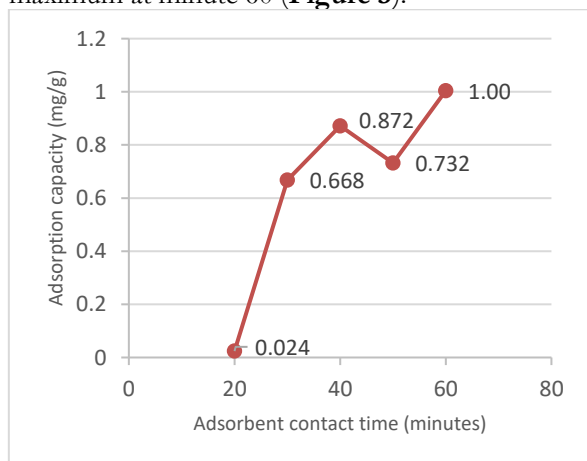


Figure 3. Relationship curve of adsorbent contact time variation on the adsorption capacity of remazol red dye

At the beginning of the process, many active sites are available, allowing for rapid interaction between the remazol red molecules and the biochar surface. Over time, the active sites fill up, and diffusion barriers can come into play. If desorption (re-release) of the dye occurs, it will temporarily decrease the adsorption capacity. The functional groups on the biochar (C=C, C-N, C-O, C-H) will continue to interact with the dye molecules until equilibrium is reached. The resulting uptake shows up-and-down behaviour due to adsorption dynamics. When the adsorbent surface is still bare, the adsorption rate is usually high because many active sites are available for dye molecules. This is what causes the adsorption to increase. As the active sites fill up, the adsorption rate will decrease. This happens because most dye molecules are bound, leaving only a few for adsorption. This can cause adsorption to start dropping. Another factor that makes adsorption go up and down is that the efficiency of biochar in adsorbing the adsorbate decreases with contact time because the adsorbent has reached saturation and is no longer able to adsorb the adsorbate (Maylani et al., 2023).

Physical adsorption occurs during the remazol red decolourisation process, where dye

molecules interact with the biochar surface via van der Waals forces, which are reversible and rapid. Similar results were obtained in a study on the adsorption of methylene blue by biochar, in which the adsorption continued to increase with contact time (Pratama et al., 2025).

Maximum pH analysis

Determination of the maximum pH is an important factor in the dye waste adsorption process because pH affects adsorption efficiency. The maximum pH needs to be determined to identify the most suitable conditions for dye absorption by the adsorbent. Figure 4 shows that the higher the pH, the lower the adsorption process of remazol red dye, meaning that remazol red is maximally adsorbed at low pH (acidic conditions).

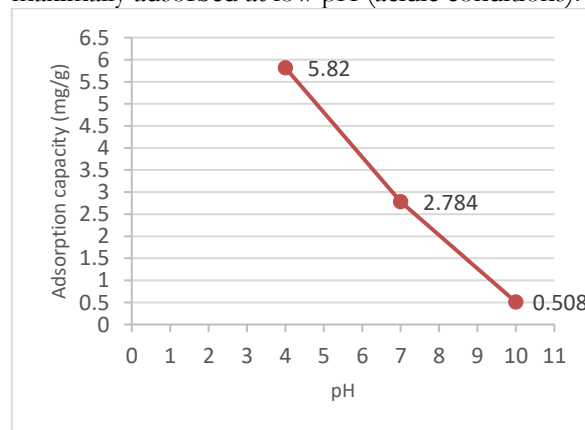


Figure 4. Relationship curve of pH variation on the adsorption capacity of remazol red dye

Remazol red dye adsorption shows that the adsorbent surface is protonated at low pH and deprotonated at high pH. At low pH (acidic conditions), the concentration of H^+ ions is higher. The high adsorption rate under acidic conditions is due to increased protonation, which neutralises the negative charge on the adsorbent surface, thereby facilitating diffusion within the adsorbent (Fitriansyah et al., 2021).

When the pH is low, the biochar surface containing -COOH groups becomes $-COOH_2^+$, so the surface charge is neutral or even positive. This increases electrostatic attraction to anionic colour ions, such as the sulfonate ($-SO_3^-$) of remazol red, thereby facilitating adsorption. As pH increases, the biochar surface is deprotonated to $-COO^-$, repelling anionic ions and decreasing adsorption. Similar results were obtained in previous studies on the absorption of brilliant red remazol dyes, which showed that the highest adsorption capacity was achieved at low pH or under acidic conditions (Shukor et al., 2022).

Overall, optimal variables exist because the adsorption process is a complex phenomenon influenced by the properties of the adsorbent and adsorbate, as well as environmental conditions. Optimising these variables enables the most

effective and efficient utilisation of active sites on biochar for dye removal from water.

Isothermal adsorption

Adsorption isotherms measure the capacity of an adsorbent to bind an adsorbate. Adsorption equilibrium isotherm data are very important for formulating equations that describe the equilibrium relationship, enabling the determination of the mass of adsorbate adsorbed by the adsorbent (Pontoh et al., 2024).

The Langmuir and the Freundlich adsorption isotherm equations were obtained to describe the adsorption of remazol red dye by kapok randu branch biochar. The Langmuir adsorption isotherm curve above shows linearity for remazol red dye uptake, with $R^2 = 0.8901$. As for the Freundlich adsorption isotherm curve, the correlation $R^2 = 0.9268$ was obtained, indicating linearity in the uptake of remazol red dye. The results for the Langmuir and the Freundlich adsorption isotherms are shown in **Figures 5 and 6**.

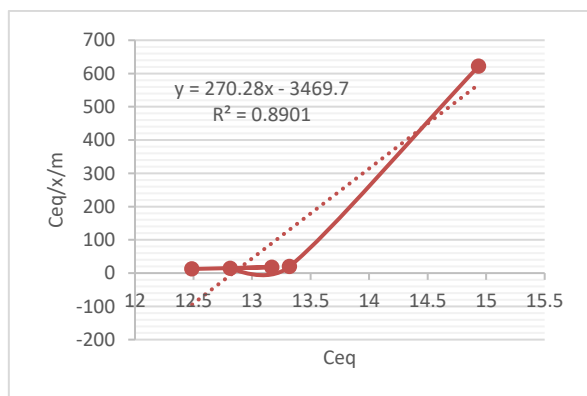


Figure 5. Langmuir linearity curve for remazol red dye adsorption

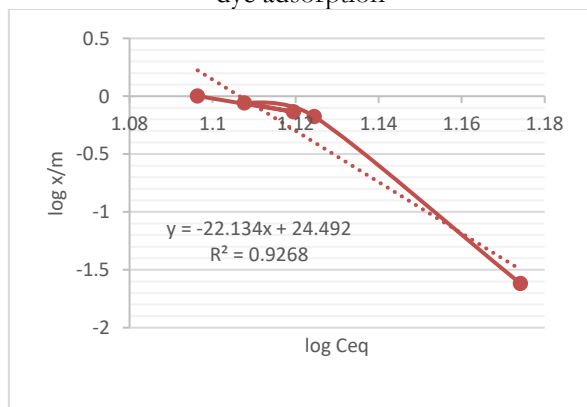


Figure 6. Freundlich linearity curve for remazol red dye adsorption

Based on the results of the linearity analysis of the Langmuir and the Freundlich isotherm models, it is evident that the Freundlich isotherm model is more suitable for describing the adsorption of remazol red dye using kapok randu biochar branches than the Langmuir isotherm model. This is because the correlation (R^2) of the Freundlich isotherm is closer to 1, namely 0.9268, so that the

adsorption system is multilayer. Multilayer adsorption involves the formation of two, three, or more stacked layers of adsorbate molecules on the adsorbent surface (Setyorini et al., 2023).

The Freundlich isotherm describes adsorption on heterogeneous (nonuniform) adsorbent surfaces, where the adsorption capacity and energy on each surface differ. The Freundlich model also allows interactions between adsorbate molecules after the first layer is formed, so that further adsorption can occur on previously adsorbed molecules. This means that remazol red molecules can be attracted to and adsorbed onto the surface of biochar through Van der Waals interactions, and further molecules can attach to the already adsorbed remazol red, forming the next layer (Indah et al., 2022).

Conclusions

Biochar adsorption from kapok randu branches follows a multilayer Freundlich isotherm model, with maximum adsorption capacity for remazol red dye (25 mg) within 60 minutes at pH 4 (acidic conditions). The use of kapok randu branches as a local raw material source for biochar production can make a significant contribution to the development of an environmentally friendly method to deal with dye pollution in water and increase the sustainability and availability of biochar at the local level.

Conflict of Interest

The author declares no conflict of interest.

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